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Twenty-year Natural Regeneration Following Five Silvicultural Prescriptions in Spruce-Fir Forests of the Intermountain West

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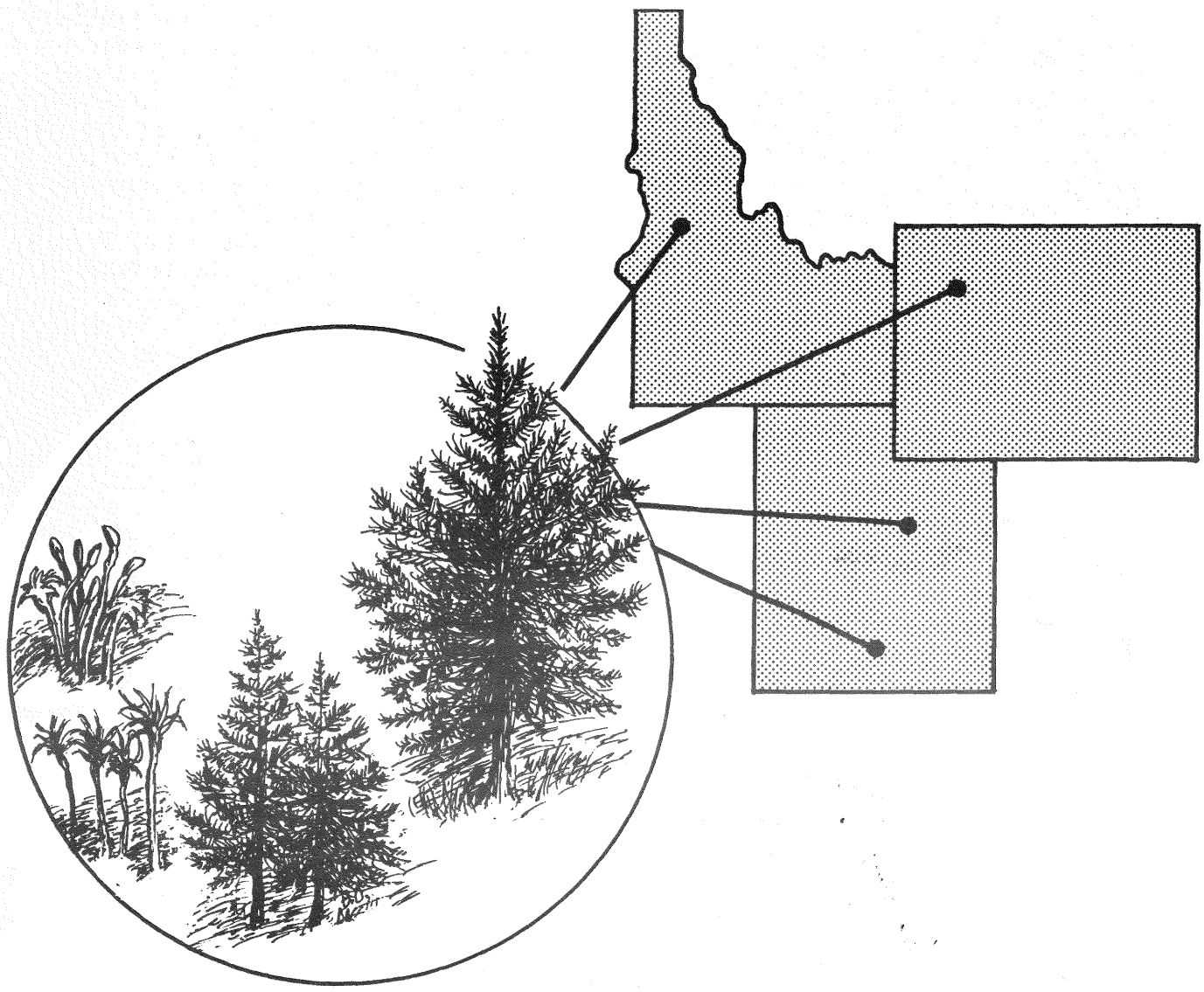

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RESEARCH SUMMARY

This study evaluates natural regeneration establishment, 20 years after five harvest cutting-site preparation treatments in Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)-subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) forests of the Intermountain West. The five treatments—clearcut-scarify, clearcut-broadcast burn, clearcut-no site preparation, partial cut-scarify, and partial cut-no site preparation—were evaluated after 20 years to determine the stocking and density of established seedlings at four study sites in Idaho, Wyoming, and Utah. Partial cutting treatments tended to favor the establishment of spruce and fir more than did clearcutting. Seedbeds providing the most favorable conditions for seedling establishment were: mineral on the Payette, burned and litter on the Teton, litter and mineral on the Uinta, and litter on the Dixie National Forest. The high number of seedlings <5 years old show that these high-elevation sites remain receptive to regeneration up to at least 20 years after harvest, although mortality continues through the first 5 to 10 years after seedling establishment.

These results provide further evidence that achieving adequate natural regeneration in the spruce-fir type is a gradual accumulative process. Supplemental planting may be needed if acceptable stocking levels are to be reached in a reasonable time.

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INTRODUCTION

Experience shows that natural regeneration establishment following harvest cutting is a slow process in high-elevation Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)-subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) forests. These forest communities are difficult to regenerate naturally following harvest cutting (Alexander 1966; Roe and Schmidt 1964). In the Intermountain region of the Rockies, this forest type comprises a large proportion of the timber resource. Spruce beetle (*Dendroctonus rufipennis* [Kirby]) epidemics in the 1950's caused substantial mortality in these forests, and managers responded with harvest cuttings aimed at salvaging mortality and removing beetle-susceptible host trees. Because of the short time managers had to salvage dead trees, cutting was seldom done as part of a well-defined silvicultural system. Many harvested areas failed to regenerate or were slow in regenerating.

Widespread regeneration failures highlighted the need for more information about natural regeneration processes in spruce-fir forests. Subsequent studies assessed the extent of the problem and delineated some of the apparent causes of regeneration failures. Results of these studies (Roe and Schmidt 1964; Roe and others 1970) pointed out the importance of seedbed, local environment, and seed supply factors in determining the ultimate success or failure of natural regeneration in the spruce-fir zone. The need to evaluate these factors silviculturally prompted a joint study by the Intermountain Region and Intermountain Research Station of the U.S. Department of Agriculture, Forest Service, to determine the long-term effects of several combinations of harvest cutting and site preparation methods on natural seedling establishment. The study was established on four widely separated areas of the Intermountain Region—the Payette, Bridger-Teton, Uinta, and Dixie National Forests.

The primary objectives of this study, started in 1967, were to:

1. Evaluate the growth response of advance understory trees to release following clearcutting and partial cutting.
2. Evaluate the effects of five harvest cutting-site preparation treatments on subsequent natural regeneration establishment.

McCaughey and Schmidt (1982) reported the results of the first objective; Fiedler and others (1985) reported 10-year results of the second. This paper reports the results of a 20-year remeasurement of subsequent regeneration on the four study areas.

METHODS

Five harvest cutting-site preparation treatments, with two replications, were installed on each of four study areas in 1967. The overall study design was a 4 x 5 factorial, with two replications per cell.

Source of variation	Degrees of freedom
Forests	3
Treatments	4
Interaction (forests x treatments)	12
Error	20
Total	39

The five treatments were:

1. Clearcutting with dozer scarification (CCS)
2. Clearcutting with broadcast burning (CCB)
3. Clearcutting with no site preparation (CCO)
4. Partial cutting with dozer scarification (PCS)
5. Partial cutting with no site preparation (PCO)

Each treatment was applied to two rectangular (10- by 20-chain) 5-acre units, for a total of 10 treatment units per study area. Treatments were separated by an uncut buffer area of at least 200 feet wide. Twenty 1-milacre regeneration plots (6.6 by 6.6 ft)

were established in each treatment unit, for a total of 40 plots per treatment. Plots were randomly established in each 5-acre unit by superimposing a grid over the treatment unit map and randomly selecting coordinate pairs.

Species and age were recorded for all subsequent seedlings on each plot. Each plot was also classified as to habitat type and was assigned the cutting method and site preparation method applied to the 5-acre treatment unit.

Study Areas

The overall study area extended approximately 425 north-south air miles from southern Utah to south-central Idaho and 325 east-west air miles from south-central Idaho to western Wyoming. The locations of the four study areas were: Payette National Forest (Payette) in Idaho, Teton National Forest (Teton) in Wyoming, Uinta National Forest (Uinta) in central Utah, and Dixie National Forest (Dixie) in southern Utah. Table 1 shows the descriptions for elevation, aspect, slope, preharvest stand composition, mature stand age, residual basal area, and habitat type for the four study areas.

Treatment Establishment

The original intent of the study was that harvest and site preparation treatments on the four forests would be accomplished in 1967. Because of weather and other problems, some exceptions to the original schedule occurred:

Payette—Burning was unsuccessful in November 1967; it was completed in September 1968.

Uinta—Three scarification treatments were completed in 1968 and one in July 1969.

Dixie—Burning was done in the fall of 1968.

DATA ANALYSIS

We describe natural regeneration establishment of Engelmann spruce and subalpine fir seedlings, using percentage milacre stocking and seedling density per acre. Stocking and density of seedlings 2 to 4, 5 to 10, and 11 to 20 years old are compared between treatments 20 years after harvest. First-year seedlings were not included in the analyses because of the probability of high mortality and the scarcity of seedlings (Alexander 1984; Noble and Alexander

Table 1—Study area descriptions for the Payette, Teton, Uinta, and Dixie National Forests

	National Forest			
	Payette	**Teton**	**Uinta**	**Dixie**
Elevation (ft)	6,000	8,600	9,500	10,300
Aspect	W to SW	N	N	level
Slope (percent)	0-30	0-50	10-30	0-10
Preharvest stand composition	77% ES 18% SAF 5% LPP	85% ES 8% SAF 3% LPP 3% PF 1% DF	95% ES 5% SAF	90% ES 10% SAF
Mature stand age	200	200-300	all aged	all aged[1]
Residual BA (ft^2/acre)				
(a) uncut	129	132	146	141
(b) partial cut	29	82	109	40
(c) clearcut	—	—	—	—
Habitat type	ABLA/XETE,[2] VASC phase ABLA/XETE, VAGL phase ABLA/CACA, LICA phase	ABLA/VAGL[3] ABLA/ACRU ABLA/STAM	ABLA/BERE,[4] BERE phase	ABLA/RIMO,[4] RIMO phase

[1]Hanley and others (1975).
[2]Steele and others (1981).
[3]Steele and others (1983).
[4]Pfister (1972).

1977). Because 5-year and older seedlings in spruce-fir forests are considered established and likely to survive to maturity (Noble and Ronco 1978), they were used to evaluate between-treatment differences. Regeneration data were compared between plots on clearcuts and partial cuts based on the site preparation treatment they received.

Wide variability in both stocking levels and seedling counts required data transformation. Stocking expressed as a proportion was transformed (arc sine $\sqrt{\text{proportion}}$) to stabilize the variance (Snedecor and Cochran 1980). Zero proportions were counted as a value of $[1/(4n)]$ before transforming to improve equality of variance (Bartlett 1947). The nonhomogeneous variance of density data was stabilized using the transformation ($\sqrt{\text{density} + 1}$) because of some zero seedling counts (Snedecor and Cochran 1980).

Analysis of variance methods showed both stocking and density varied significantly ($p = 0.05$ level) between forests. Therefore, further analysis was conducted on a forest-by-forest basis.

Multiple comparison procedures were used to analyze between-treatment differences in stocking and density. To control the maximum experimentwise error rates, we used the Ryan-Einot-Gabriel-Welsch multiple F test procedure for equal cell sizes and the Tukey-Kramer method for unequal cell sizes (SAS Institute Inc. 1987).

Data were analyzed using four age classes of seedlings: (1) 2- to 4-year-olds, which represent continuing seedbed receptiveness; (2) 5- to 10-year-olds, which represent seedling establishment in the period 10 to 20 years after harvest; (3) 11- to 20-year-olds, which represent seedling establishment in the period 1 to 10 years after harvest; and (4) 5-years and older, which represent all established seedlings 20 years after harvest. Forty 1-milacre plots per treatment were used to analyze between-treatment differences at the stand level for each forest.

RESULTS AND DISCUSSION

Previous 10-year results showed that stocking by natural regeneration is a gradual accumulative process in spruce-fir forests (Fiedler and others 1985). Results of the 20-year remeasurement corroborate that this is a slow ecological process.

Many plots established in 1967 and remeasured at year 10 could not be found for the 20-year remeasurement. Each lost plot was reestablished using the randomly selected coordinates that were used to establish the plot 20 years earlier. The reestablished plots may or may not have duplicated the exact initial plot locations; therefore, the results of the 10- and 20-year remeasurements were not directly comparable. Consequently, the results reported in this paper are based on the 20-year remeasurement only.

The following section describes natural regeneration 20 years after harvest for five silvicultural treatments on four national forests.

Stocking and Density—Between Treatments

Seedlings 2 to 4 Years Old—There were no significant differences in milacre stocking and seedling density between cutting methods on any forest for 2- to 4-year-old seedlings. Lack of significance between treatments was due to high within-treatment variance of seedling density and milacre stocking. Partial cuts averaged 16 percent greater milacre stocking than clearcuts on all forests except the Teton (table 2). PCO and PCS treatments had higher seedling densities than any clearcut treatment on the Uinta and Dixie National Forests (table 3). The PCS treatment on the Payette had the highest seedling density followed by PCO and CCS. Seedling density on the CCB treatment was only slightly higher than on PCO treatment on the Teton National Forest.

Although 2- to 4-year-old seedlings are not considered established, their presence indicates that these sites remain receptive to natural regeneration many years after disturbance. We attribute the higher stocking levels on partial cuts to the moderating effect of overstory trees on these high-elevation sites and the close seed source.

Seedlings 5 to 10 Years Old—Five-year-old seedlings are normally considered established; however, results strongly suggest that mortality continues beyond 5 years. No statistically significant differences in milacre stocking or density were found between cutting methods on any of the four forests. Although there were absolute differences in milacre stocking, they were not as evident between partial cuts and clearcuts as they were with the 2- to 4-year-old seedlings (table 2). Stocking of 5- to 10-year-old seedlings was highest on the PCO or PCS treatments on all forests.

Even though there were sizable absolute differences in seedling density between treatments, these differences were not statistically significant due to extreme variation in seedling counts (table 3). Absolute numbers of seedlings were highest on either PCS, PCO, or both on the Payette, Teton, and Dixie National Forests. On the Uinta, seedling densities were equivalent but low (50 seedlings per acre) on all but the CCS treatment, which contained no seedlings.

Table 2—Milacre plot stocking of 2- to 4-, 5- to 10-, 11- to 20-, and 5- to 20-year-old seedlings 20 years after harvest on the Payette, Teton, Uinta, and Dixie National Forests

National Forest	Harvest cutting site preparation treatment	2- to 4-year-old seedlings	5- to 10-year-old seedlings	11- to 20-year-old seedlings	5- to 20-year-old seedlings
		Percent milacre stocking			
Payette	Clearcut-scarify	35	42	45	55
	Clearcut-broadcast burn	12	12	12	20
	Clearcut-no site preparation	27	37	30	42
	Partial cut-scarify	42	47	37	50
	Partial cut-no site preparation	40	32	40	47
Teton	Clearcut-scarify	7	20	12	22
	Clearcut-broadcast burn	12	25	15	30
	Clearcut-no site preparation	10	22	15	27
	Partial cut-scarify	7	30	22	37
	Partial cut-no site preparation	20	45	20	50
Uinta	Clearcut-scarify	0	0	5	5
	Clearcut-broadcast burn	7	5	0	5
	Clearcut-no site preparation	0	5	5	7
	Partial cut-scarify	20	5	0	5
	Partial cut-no site preparation	15	5	7	12
Dixie	Clearcut-scarify	0	10	15	15
	Clearcut-broadcast burn	0	7	2	10
	Clearcut-no site preparation	2	22	32	35
	Partial cut-scarify	7	17	17	22
	Partial cut-no site preparation	25	25	35	45

Seedlings 11 to 20 Years Old—This category is representative of spruce and fir seedlings that germinated the first 10 years after harvesting and survived until year 20. There were no statistically significant differences in either milacre stocking or seedling density between treatments on any of the four forests (tables 2 and 3).

Seedlings 5 to 20 Years Old—This age group is an aggregate of the 5- to 10- and 11- to 20-year-old seedlings. There were no statistically significant differences in milacre stocking or seedling density between cutting methods. The highest stocking in absolute terms was on the PCO treatment on the Teton, Uinta, and Dixie National Forests and on the CCS treatment on the Payette (table 2). The PCO treatment represents a minimum of seedbed disturbance along with the moderating effect of a residual overstory. The CCS and PCS were the most beneficial treatments on the Payette, probably because they effectively reduced competition from beargrass (*Xerophyllum tenax*). The highest seedling densities were on the PCS treatments on the Payette, the PCO treatment on the Teton and Uinta, and on the CCO treatment on the Dixie National Forest (table 3).

Stocking-Density Relationships

Seedling density was significantly correlated (p-value ≤ 0.10) to milacre stocking on all forests

Table 3—Seedling density of 2- to 4-, 5- to 10-, 11- to 20-, and 5- to 20-year-old seedlings 20 years after harvest on the Payette, Teton, Uinta, and Dixie National Forests

National Forest	Harvest cutting site preparation treatment	2- to 4-year-old seedlings	5- to 10-year-old seedlings	11- to 20-year-old seedlings	5- to 20-year-old seedlings
		Seedlings per acre			
Payette	Clearcut-scarify	925	1,375	1,100	2,475
	Clearcut-broadcast burn	200	150	200	350
	Clearcut-no site preparation	625	700	1,325	2,025
	Partial cut-scarify	1,775	1,800	1,100	2,900
	Partial cut-no site preparation	900	950	925	1,875
Teton	Clearcut-scarify	300	450	125	575
	Clearcut-broadcast burn	1,075	850	175	1,025
	Clearcut-no site preparation	200	600	175	775
	Partial cut-scarify	75	600	250	850
	Partial cut-no site preparation	1,025	1,600	450	2,050
Uinta	Clearcut-scarify	0	0	100	100
	Clearcut-broadcast burn	75	50	0	50
	Clearcut-no site preparation	0	50	50	100
	Partial cut-scarify	450	50	0	50
	Partial cut-no site preparation	325	50	75	125
Dixie	Clearcut-scarify	0	175	250	425
	Clearcut-broadcast burn	0	75	25	100
	Clearcut-no site preparation	50	325	725	1,050
	Partial cut-scarify	300	425	275	700
	Partial cut-no site preparation	500	400	475	875

20 years after harvest. A quadratic function best fit the combined stocking-density data for 2- to 4-, 5- to 10-, and 11- to 20-year-old seedlings on all forests 20 years after harvest (fig. 1). Density increased at an increasing rate with stocking for all age classes. For example, at 10 percent stocking, virtually all stocked plots had only one 11- to 20-year-old seedling per plot, whereas at 40 percent stocking, each stocked plot averaged well over two seedlings in this age class (extracted from figure 1). Harris (1967) and Seidel (1979) also reported increased density with increasing stocking levels. Densities of 5- to 10- and 11- to 20-year-old seedlings were similar to, but lower than, densities of 2- to 4-year-olds on both clearcuts and partial cuts.

Seedbed Relationships

Although not statistically significant, apparent stocking differences occurred between cutting methods for two site preparation treatments. On every forest the highest stocking on mineral seedbeds occurred in combination with clearcutting; conversely, on litter seedbeds the highest stocking occurred with partial cutting (table 4). Although burned seedbeds occurred on clearcuts only, stocking was lower than on mineral or litter seedbeds on every forest except the Uinta, where stocking on burned and litter seedbeds was similar and lower than on mineral seedbeds (table 4).

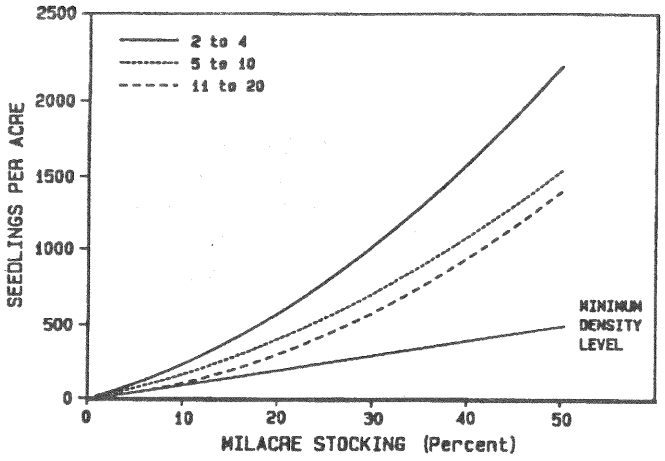

Figure 1—Relationship of milacre stocking to seedling density for 2- to 4-, 5- to 10-, and 11- to 20-year-old seedlings on clearcuts and partial cuts on the Payette, Teton, Uinta, and Dixie National Forests. The minimum density line represents the stocking-density relationship if there was only one seedling on each milacre plot.

Seedling Density Over Time

The age structure of seedlings was examined on each forest relative to cutting method. Although seedling density varied among forests, overall density was sharply higher on partial cuts than on clearcuts on every forest (figs. 2 and 3). The pattern of gradually increasing density over time held for both cutting methods on every forest except the Uinta, where seedling establishment in partial cuts paralleled that on the Teton and Dixie Forests until year 5. Beyond year 5, additional regeneration was nil. On the Uinta, the major causes of seedling mortality probably were pocket gophers and sheep grazing, which may account for this atypical regeneration pattern.

Higher mean seedling densities on partial cuts versus clearcuts suggest that this method may be better for regeneration establishment. But this result must be evaluated in relation to the vigor and growth rate of the regeneration stand and the stability of the residual stand before partial cutting can be generally recommended.

Table 4—Milacre stocking of 5-year and older seedlings on mineral, burned, and litter seedbeds in clearcut and partial cuts on the Payette, Teton, Uinta, and Dixie National Forests

National Forest	Cutting method	Seedbed condition					
		Mineral		Burned		Litter	
		Percent					
Payette	Clearcut	55 a[1]	(0.9105)[2]	26 a		37 a	(0.6677)
	Partial cut	55 a		—		46 a	
Teton	Clearcut	33 a	(0.9009)	23 a		38 a	(0.4144)
	Partial cut	31 a		—		56 a	
Uinta	Clearcut	16 a	(0.7065)	2 ab		2 b	(0.0885)
	Partial cut	10 a		—		25 a	
Dixie	Clearcut	31 a	(0.6657)	6 a		23 a	(0.0870)
	Partial cut	15 a		—		43 b	

[1]Seedbed stocking values within a cutting method, sharing a common letter within a row, are not significantly different (p-value ≤ 0.10).

[2]Values in parentheses represent p-values for significant differences between cutting methods within a seedbed condition on a forest.

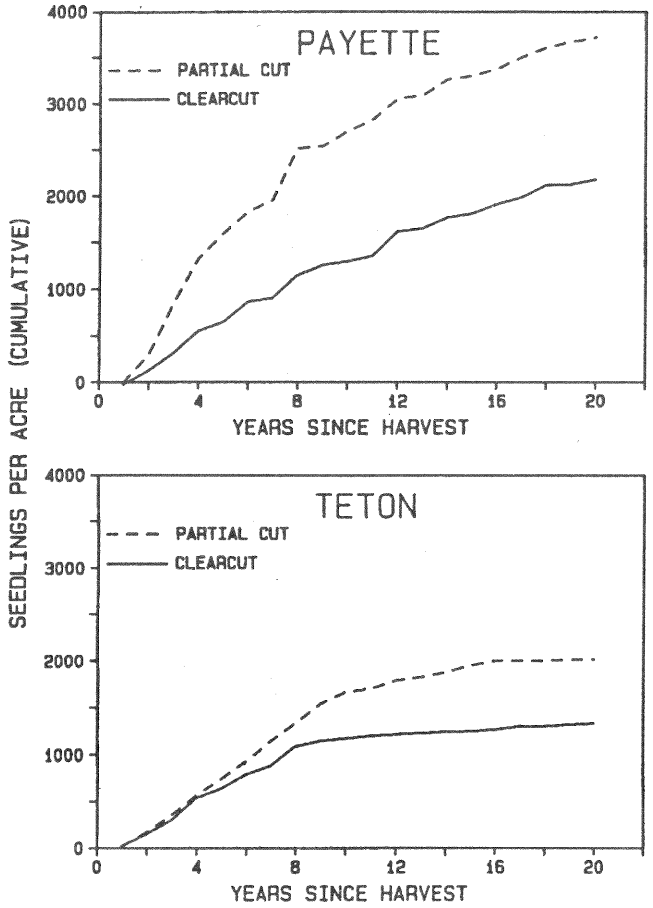

Figure 2—Cumulative seedlings per acre from 1 to 20 years after harvest on clearcuts and partial cuts on the Payette and Teton National Forests.

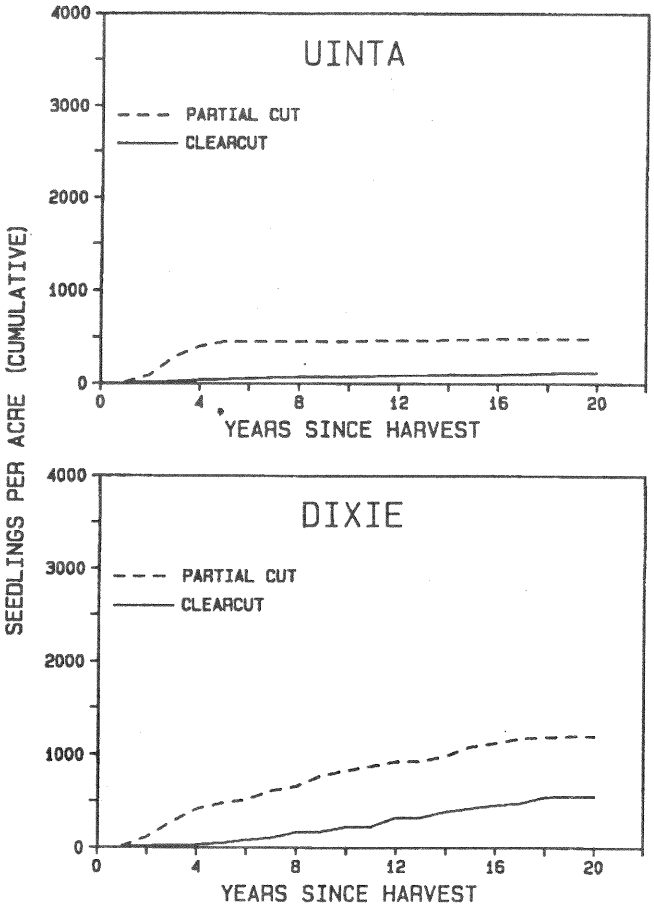

Figure 3—Cumulative seedlings per acre from 1 to 20 years after harvest on clearcuts and partial cuts on the Uinta and Dixie National Forests.

Changes in seedling density over time were also examined relative to seedbed condition on each forest. On the Payette, seedling density was highest on mineral soil seedbeds throughout the 20-year period (fig. 4). On all other forests, density was as high or higher on litter seedbeds as on any other seedbed condition (figs. 4 and 5). Seedling densities remained extremely low on burned seedbeds even at year 20 on all forests except the Teton. Although prescribed burning may be an efficient slash disposal method, low seedling establishment rates suggest that this method is not an optimum technique for regenerating Intermountain spruce-fir forests.

Stocking by Species

Overall stocking of Engelmann spruce (all treatments combined) was lower than stocking of subalpine fir on all forests except the Uinta, where stocking of both species was negligible. This result is dramatic when viewed in context of the species composition of the seed source. The ratio of Engelmann spruce:subalpine fir seed source (basal area) was compared to the corresponding species ratio of established seedlings on each forest. Ratios of spruce:fir were 4:1 (seed source) versus 1:1 (established seedlings) on the Payette, 10:1 versus 1:2 on

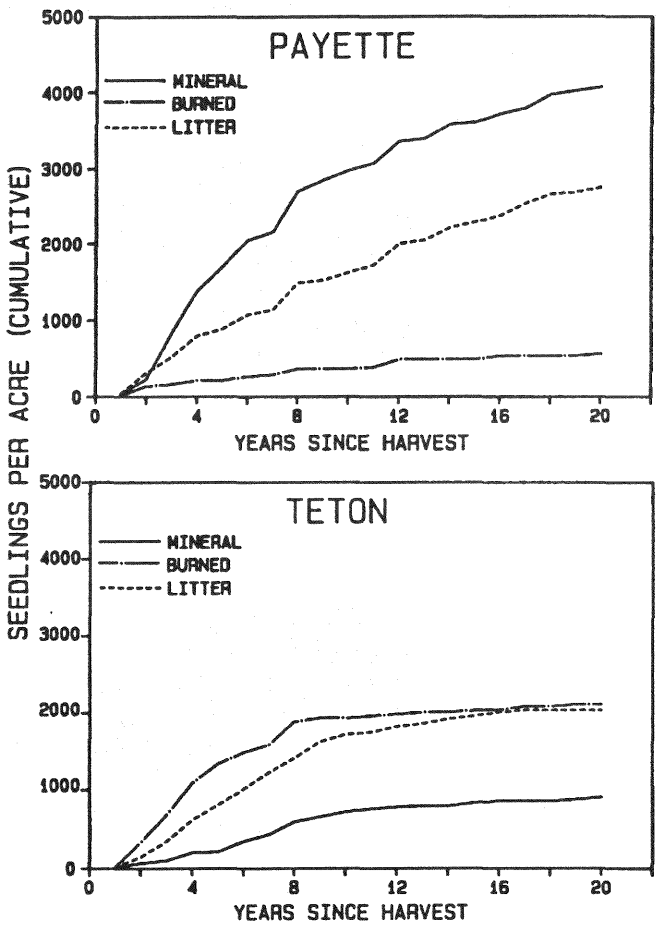

Figure 4—Cumulative seedlings per acre from 1 to 20 years after harvest on mineral, burned, and litter seedbeds on the Payette and Teton National Forests.

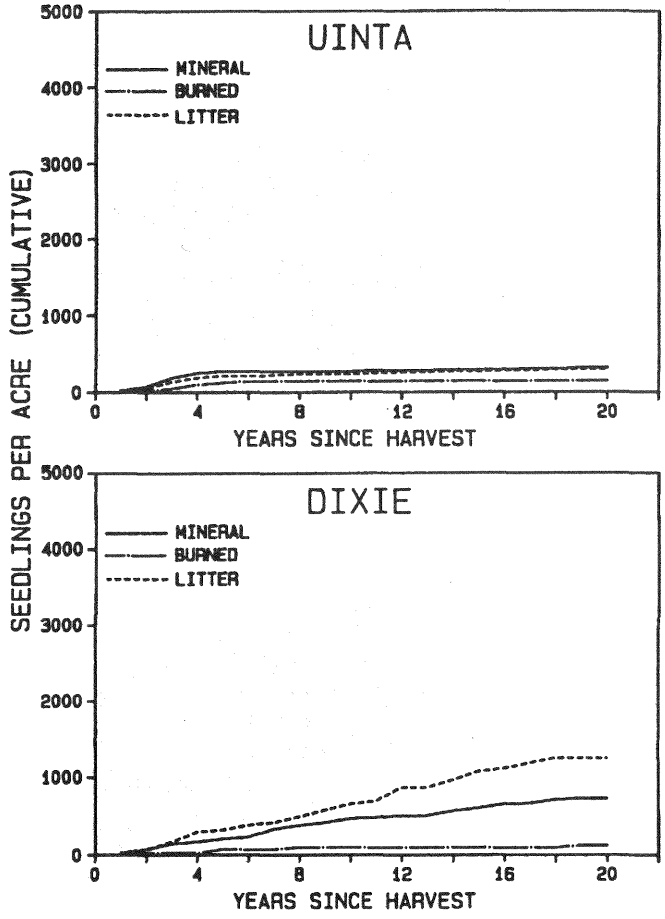

Figure 5—Cumulative seedlings per acre from 1 to 20 years after harvest on mineral, burned, and litter seedbeds on the Uinta and Dixie National Forests.

the Teton, 19:1 versus 3:1 on the Uinta, and 9:1 versus 1:2 on the Dixie, respectively (fig. 6). When differences in seed source were accounted for, subalpine fir had a far greater stocking efficiency on every forest. The ratio of subalpine fir to Engelmann spruce seedlings per unit area of seed source varied from 4:1 on the Payette, 20:1 on the Teton, 6:1 on the Uinta, and 18:1 on the Dixie (fig. 6).

Stocking of Engelmann spruce and subalpine fir varied by treatment and location. There was only a slight stocking advantage for subalpine fir over Engelmann spruce on CCO and PCO treatments on the Teton, Uinta, and Dixie National Forests (table 5). Litter lessens the impact of high-intensity summer storms and provides protection from frost heaving (Fiedler and others 1985), a common phenomenon on high elevation mineral seedbeds. Studies in the Canadian (Day 1963), Northern (Hanley and Pfister 1983; Roe and others 1970), and Central Rocky Mountains (Knapp and Smith 1982) have reported drought as a major cause of spruce seedling mortality on litter seedbeds, primarily due to slow first year root growth. Roe and Schmidt (1964), however, reported that moisture generally did not appear critical to seedling survival in Intermountain spruce-fir forests.

Results represent a specific habitat type-slope-elevation combination on each forest, and should not be used indiscriminately over a wide range of stand conditions.

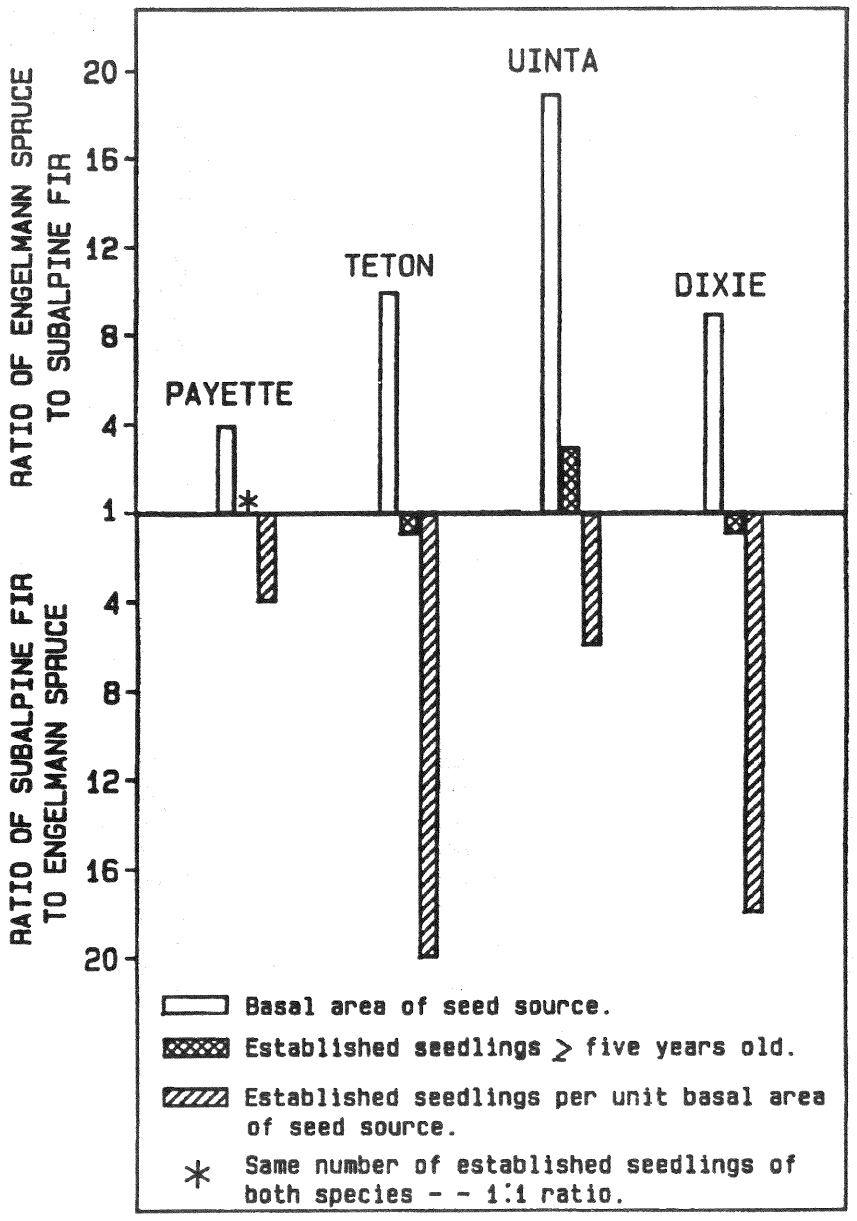

Figure 6—Ratios of Engelmann spruce to subalpine fir (and subalpine fir to Engelmann spruce) in terms of basal area of seed source, established seedlings, and established seedlings per unit basal area of seed source, on the Payette, Teton, Uinta, and Dixie National Forests.

Table 5—Milacre plot stocking of 5- to 20-year-old Engelmann spruce and subalpine fir seedlings 20 years after harvest on five harvest-cutting-site preparation treatments on the Payette, Teton, Uinta, and Dixie National Forests

National Forest	Harvest cutting site preparation treatment	Engelmann spruce	Subalpine fir	Total spruce and fir
		Percent milacre stocking		
Payette	Clearcut-scarify	36	37	55
	Clearcut-broadcast burn	15	7	20
	Clearcut-no site preparation	35	22	42
	Partial cut-scarify	40	42	50
	Partial cut-no site preparation	20	42	47
Teton	Clearcut-scarify	17	10	22
	Clearcut-broadcast burn	12	27	30
	Clearcut-no site preparation	15	20	27
	Partial cut-scarify	10	30	37
	Partial cut-no site preparation	17	42	50
Uinta	Clearcut-scarify	5	2	5
	Clearcut-broadcast burn	5	0	5
	Clearcut-no site preparation	5	2	7
	Partial cut-scarify	5	0	5
	Partial cut-no site preparation	10	2	12
Dixie	Clearcut-scarify	10	12	15
	Clearcut-broadcast burn	7	2	10
	Clearcut-no site preparation	5	32	35
	Partial cut-scarify	7	15	22
	Partial cut-no site preparation	12	40	45

CONCLUSIONS

Results of this study indicate that high-elevation forests of the Intermountain Region remain receptive to spruce and fir regeneration for at least 20 years. Results are consistent with findings of other shorter-term regeneration studies in this zone. Our earlier 10-year results (Fiedler and others 1985), along with Noble and Ronco (1978) in Colorado, Fiedler (1980) in Montana, and Minore and Dubrasich (1981) in Oregon, indicate that natural regeneration of spruce and fir is a slow process following disturbance in subalpine forests.

No single combination of harvest cutting and site preparation assures regenerating spruce-fir forests in Idaho, Wyoming, and Utah. Instead, after 20 years, prescriptions for greatest natural regeneration following harvest cuttings are forest and stand specific:

1. On the Payette, both clearcutting and partial cutting can be used successfully, with partial cutting producing more seedlings. Prescribed burning apparently created too harsh a condition for seedling establishment. Scarification produced the most favorable condition for natural regeneration because of the reduction in competition from associated vegetation. Doing little or no site preparation also appears to be effective.
2. On the Teton, both clearcutting and partial cutting can be used but partial cutting provides a more favorable condition for seedling establishment. As opposed to the Payette, lightly burning the slash or doing nothing with the litter appear to be the best options.
3. On the Uinta, a light partial cutting appears to be the only silvicultural option. Even with partial cutting it is difficult to successfully regenerate

this area, especially when grazed by domestic stock. It is hard to say just how well regeneration would establish without animal damage. At this point it appears that leaving the organic layer intact is the best option. Another option may be to exclude livestock during the regeneration period.

4. On the Dixie, partial cutting appears to be the best harvest-cutting option and leaving the organic layer intact the best seedbed. This area is subject to extreme weather and site conditions, and the more protection that can be provided for regeneration the better. Prescribed burning or scarification after clearcutting appear to be very poor options on this area.

Several factors do stand out 20 years after harvesting and seedbed treatment in spruce-fir forests of the Intermountain area. In general:

1. Partial cutting resulted in more regeneration than clearcutting.
2. Prescribed burning was not beneficial for regeneration on most sites.
3. Scarification was helpful on the Payette. On the more severe, higher elevation sites it was harmful.
4. Regeneration of both spruce and fir accumulates slowly; however, subalpine fir regenerates far more successfully when comparable seed sources are available.
5. Mortality appears to occur well beyond 5 years but at a decreasing rate.
6. Planting may be necessary to augment regeneration if the gradual natural restocking is not compatible with management objectives of these high-elevation forests.

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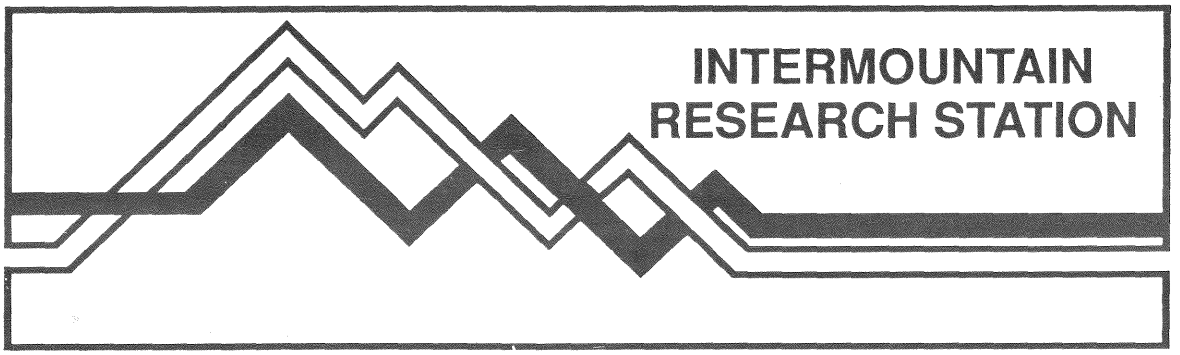
No single combination of five cutting-site preparation treatments resulted in superior natural regeneration in spruce-fir stands in Wyoming, Utah, and Idaho. Best results were generally obtained by partial cutting, with minimal disturbance of litter and organic matter, especially on harsh, high-elevation sites. Most sites remained receptive to natural regeneration; however, high seedling mortality resulted in slow accumulation of established seedlings on all treatment combinations. For optimum natural regeneration, silvicultural prescriptions must be stand and forest specific.

KEYWORDS: *Picea engelmannii*, *Abies lasiocarpa*, site preparation, clearcutting, partial cutting, natural regeneration



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